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Quantification of Root-Shoot Development and Water Use Efficiency in Autumn Maize (*Zea mays* L) Under Different Irrigation Strategies

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Abstract: A field study was conducted to evaluate the productivity of autumn-sown maize hybrids (Monsanto-919 and Pioneer-30Y87) under variable irrigation regimes. The experiment was laid out in randomized complete block design (RCBD) with factorial arrangement with the following treatments; I_1 = control, I_2 = 4 irrigations (6^{th} 10^{th} 14^{th} 18^{th} leaf stages), I_3 = 6 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking and blister stages), I_4 = 8 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking, blister, milking and dough stages), I_5 = 10 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking, blister, milking, dough, denting and physiological maturity). The hybrids differ significantly for primary root numbers, root length, roots dry weight, water use efficiency for total dry matters (WUE_{TDM}), while water use efficiency for grain yield (WUE_{GY}) were found non-significant in both hybrids. Irrigation level I_2 produced significantly higher primary root numbers (20.83 roots per plant) which were statistically at par with irrigation level I_1 (20.66), whereas, Irrigation level I_1 produced significantly more root length (548.67cm) than the irrigation treatments I_2 (476.17) and I_3 (434.33). Similarly, Irrigation level I_1 attained maximum root dry weight plant^{-1}(0.71mg) than I_2 (0.67mg) and I_3 (0.59mg). Among irrigation treatments, more water use efficiency for total dry matters was obtained in treatments I_3, I_4, I_5. The range of water use efficiency for total dry matters for these treatments was 6.18 to 6.42. Highly-significant values were found in water use efficiency for grain yield. Treatments I_3, I_4 and I_5 were good at producing more grain yield per unit water transpired.

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1. Introduction

Maize (*Zea mays* L.) is the 3rd most significant cereal crop in the world after wheat and rice (Ullah et al., 2007). It can be easily adjusted in crop rotation due to its short life span and can be cultivated twice in a year. Water is the major yield limiting factors in agricultural system especially in arid and semi-arid regions. Among various abiotic and biotic stress factors, drought is an important yield limiting factor for maize because of genotype by environmental interactions in maize at spatiotemporal scale. Drought is a permanent constraint to agricultural production in many developing countries, and also in developed countries (Khodarahmpour and Hamidi, 2011). Drought is one of the most critical abiotic stresses which affect almost every aspect of plant growth and development, and ultimately resulted in reduced plants productivity (Pan et al., 2002; Farooq et al., 2009). However, crop productivity can be sustained, up to certain level, by manipulating different crop management practices in a way to avoid or reduce the impact of drought stress.

Rapidly increasing population pressure and climatic change has made water more important in many parts of the world (Malik et al., 2010). It is, therefore, likeable to make research plans to investigate available crop genotypes for their ability to withstand water deficit. The availability of less water plays an important role in reducing yield. It is better to increase water use efficiency of crops rather applying heavy irrigation under changing climate scenario where shortage of water is main cause of drought (Samiha et al., 2009).

In plants drought can cause numerous structural, physiological and biochemical modifications including reduction in leaf area, stem extension, root proliferation, reduced water use efficiency (Farooq et al., 2009), alteration in metabolic activities (Lawlor and Cornic, 2002), inhibition of enzymatic activities, imbalanced ionic concentration and interruption in accumulation of various solutes (Khan et al., 1999). These responses may occur alone or a combination of all these factors (Ali et al., 2011) depending upon the severity, frequency and duration of drought.

Considering the importance and irregular availability of water in Pakistan, especially under changing climate, this study was conducted to evaluate the impact of different irrigation schedules on growth of roots, shoots and productivity of maize in addition to find out water use efficiency of maize under different irrigation treatments and to quantify the behavior of roots and shoots.

2. Materials and Methods

A field experiment was conducted at Agronomic Research Area, University of Agriculture, Faisalabad, during autumn season of 2011. Before sowing of crop a composite soil sample (up to 30 cm depth) was collected from the experimental area with soil auger and analyzed to assess physico-chemical properties of soil at experimental site (Table 1). The experiment was laid out in RCBD with factorial arrangement. Two maize hybrids i.e., Monsanto-919, Pioneer-30-Y-87. Different irrigation Schedules I_1 = Control, I_2 = 4 irrigations (6th 10th 14th 18th leaf stages), I_3 = 6 irrigations (6th , 10th,14th, 18th leaf stages, silking and blister stages), I_4 = 8 irrigations (6th , 10th,14th, 18th leaf stages, silking, blister, milking and dough stages), I_5 = 10 irrigations (6th , 10th,14th, 18th leaf stages, silking, blister, milking, dough, denting and physiological maturity) were imposed on two maize hybrids (Monsanto-919 and Pioneer-30Y87). Experiment was performed in triplicate with each experimental unit of 27 m^{-2} (6.0m × 4.5m). In the experiment buffer plot of 1.5 m between subplots was maintained to minimize seepage effect of irrigation among various treatments.

Table: 1 Analysis of soil in the experimental area

Soil Analysis	Unit	Measure
Physical Analysis		
Sand	%	63
Silt	%	15
Clay	%	23
Texture Class		Sandy Clay Loam
Chemical Analysis		
pH	-	7.51
Organic Matter	%	1.01
Nitrogen	%	0.069
Phosphorus	ppm	6.94
Potassium	ppm	183

Crop was sown mechanically using dibbler during the month of August on a well prepared seedbed. Maize hybrids Monsanto-919 and Pioneer 30Y87 were sown on ridges using seed rate of 25 kg ha^{-1} and uniform plant population was ensured by maintaining row × plant spacing of 75cm × 25cm with each experimental unit containing six rows. The plant population was controlled in all treatments by gap filling and thinning after germination. Local recommendations of fertilizers were applied i.e., NPK fertilizers were applied at the rate of 200 kg ha^{-1}, 100 kg ha^{-1} and 50 kg ha^{-1}, respectively. Half of N and all the P and K were applied just before sowing. Remaining half of N was applied in two splits, first at 15-days after sowing (DAS) and second at flowering. All other agronomic practices were kept uniform for all the treatments.

2.1 Calculation for Quantity of Water

Discharge of the watercourse was calculated using cut throat flume equation 1 was used for calculation of time for a specific depth of water (Mubeen et al., 2013).

$$t = A \times d/Q \qquad [1]$$

where t is time (in secods) to irrigate, A is area (m^2) of the plot to be irrigated, d is depth (m) of water to be applied and Q is discharge (m^3) of the cut throat flume.

Potential evapotranspiration was calculated from daily pan evaporation data from nearest location (observatory of Department of Crop Physiology, University of Agriculture, Faisalabad) as described earlier (Mubeen et al., 2013).

2.2 Root and shoot parameters

Plant height, stem diameter and total biomass accumulation in the shoot were determined from 10 randomly selected plants from inner rows of each experimental. Stem diameter of randomly selected plants was measured from near the soil surface. The primary root numbers were also recorded. Root biomass and root density in the soil were examined from a 50 × 40 cm^2 area on one side of a row for two plants. Soil was dug out to a depth of 60 cm to collect roots. For all experimental units roots on both sides of a row, irrigated or non-irrigated furrows were harvested.

2.3 Water Use Efficiency (WUE)

Water use efficiency (WUE) for total dry matter (TDM) and grain yield (GY) was calculated as ratio of yield and actual evapotranspiration (ETa). The ETa of the crop was calculated by multiplying the potential evapotranspiration with crop coefficient (Kc) following Doorenbos and Pruitt (1975).

2.4 Statistical Analysis

All the data was analyzed statistically using the Fisher's analysis of variance technique (Steel et al., 1997) and least significant difference test at 5 % probability level will be used to compare the significance of treatments' means.

3. Results and Discussion

3.1 Number of Seminal Roots

The effect of genotype on seminal root number was non- significant (Table 2). The Monsatno-919 gave non-significantly higher seminal root numbers (5.0) than Pioneer 30Y87 (4.46). The effect of Irrigation treatment on seminal root numbers was highly significant. Irrigation level I_1 produced significantly higher number of seminal roots (7.00) which were statistically at par with irrigation level I_2 (6.00). The lower seminal root numbers were produced in irrigation level I_5 (2.66) and I_4 (3.66) followed by I_3 (4.33).

These results are similar with Konopka et al. (2008) who reported that the lowest seminal root growth in terms of seminal root numbers were observed when number of irrigations increased, because these roots usually appears to sustain the all mechanism within the plant through possible absorption of water in case of shortage of water in root zone. The mutual effects of hybrids and irrigation level were found to be non-significant.

Table 2: **Genotype variation in response to different irrigation scheduling strategies on number of seminal root in maize hybrids**

Treatments	Number of Seminal Roots
Hybrids	
H_1 = Monsanto-919	5.00
H_2 = Pioneer-30Y87	4.46
SX	0.26
LSD 5%	0.56
Significance	NS
Irrigations	
I_1 = Control	7.00 a
I_2 = 4 Irrigations	6.00 b
I_3 = 6 Irrigations	4.33 c
I_4 = 8 Irrigations	3.66 c
I_5 = 10 Irrigations	2.66 d
SX	0.41
LSD 5%	0.88
Significance	**
Interaction	NS

Irrigation treatments: I_1 = Control, I_2 = 4 irrigations (6^{th} 10^{th} 14^{th} 18^{th} leaf stages), I_3 = 6 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking and blister stages), I_4 = 8 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking, blister, milking and dough stages), I_5 = 10 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking, blister, milking, dough, denting and physiological maturity). Means not sharing common letters in a column differ significantly at P = 0.05; NS=Non significant, * and ** are significant at 5% and 1% probability.

Table 3: **Genotype variation in response to different irrigation scheduling strategies on seminal root length (cm) in maize hybrids**

Treatments	Seminal Root Length (cm)
Hybrids	
H_1 = Monsanto-919	28.46
H_2 = Pioneer-30Y87	25.33
SX	1.58
LSD 5%	3.31
Significance	NS
Irrigations	
I_1 = Control	49.33 a
I_2 = 4 Irrigations	35.50 b
I_3 = 6 Irrigations	20.66 c
I_4 = 8 Irrigations	15.66 cd
I_5 = 10 Irrigations	13.33 d
SX	2.50
LSD 5%	5.23
Significance	**
Interaction	NS
Mean	26.99

Irrigation treatments: I_1 = Control, I_2 = 4 irrigations (6^{th} 10^{th} 14^{th} 18^{th} leaf stages), I_3 = 6 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking and blister stages), I_4 = 8 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking, blister, milking and dough stages), I_5 = 10 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking, blister, milking, dough, denting and physiological maturity). Means not sharing common letters in a column differ significantly at P = 0.05; NS=Non significant, * and ** are significant at 5% and 1% probability.

3.2 Seminal Root Length (cm)

Table (3) shows non-significant genotypic differences in seminal root length of maize hybrids. Monsanto-919 Slightly longer roots (28.46 cm) as compared to Pioneer-30Y87 (25.33 cm). The response of number of irrigation to the seminal root length was found to be highly significant. Irrigation level I_1 produced significantly more seminal root length (49.3) than I_2 (35.50) and I_3 (20.66). The minimum root length (13.33) was produced by irrigation treatment I_5 which is statistically at par with I_4 (15.66). It is clear from the above discussion that seminal root length increases as number of Irrigation treatment decreases. These results are in line with Konopka et al. (2008) who reported that the lowest root growth in terms of length were observed when number of irrigations increased as root zone saturation cannot allow roots to increase in search of water. The mutual effects of hybrids and irrigation level were found to be non-significant.

Table 4: **Genotype variation in response to different irrigation scheduling strategies on number of lateral roots in maize hybrids**

Treatments	Number of Lateral Roots
Hybrids	
H_1 = Monsanto-919	17.86
H_2 = Pioneer-30Y87	16.6
SX	0.73
LSD 5%	1.53
Significance	NS
Irrigations	
I_1 = Control	20.66 a
I_2 = 4 Irrigations	20.83 a
I_3 = 6 Irrigations	16.50 b
I_4 = 8 Irrigations	13.66 c
I_5 = 10 Irrigations	14.50 bc
SX	1.16
LSD 5%	2.42
Significance	**
Interaction	NS
Mean	17.23

Irrigation treatments: I_1 = Control, I_2 = 4 irrigations (6^{th} 10^{th} 14^{th} 18^{th} leaf stages), I_3 = 6 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking and blister stages), I_4 = 8 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking, blister, milking and dough stages), I_5 = 10 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking, blister, milking, dough, denting and physiological maturity). Means not sharing common letters in a column differ significantly at P = 0.05; NS=Non significant, * and ** are significant at 5% and 1% probability.

Table 5: **Genotype variation in response to different irrigation scheduling strategies on lateral root length (cm) in maize hybrids**

Treatments	Lateral Root Length (cm)
Hybrids	
H_1 = Monsanto-919	451.6
H_2 = Pioneer-30Y87	430.07
SX	10.47
LSD 5%	22
Significance	NS
Irrigations	
I_1 = Control	548.67 a
I_2 = 4 Irrigations	476.17 b
I_3 = 6 Irrigations	434.33 c
I_4 = 8 Irrigations	381.33 d
I_5 = 10 Irrigations	363.67 d
SX	16.56
LSD 5%	34.78
Significance	**
Interaction	NS
Mean	440.83

Irrigation treatments: I_1 = Control, I_2 = 4 irrigations (6^{th} 10^{th} 14^{th} 18^{th} leaf stages), I_3 = 6 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking and blister stages), I_4 = 8 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking, blister, milking and dough stages), I_5 = 10 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking, blister, milking, dough, denting and physiological maturity). Means not sharing common letters in a column differ significantly at P = 0.05; NS=Non significant, * and ** are significant at 5% and 1% probability.

3.3 Lateral Root Numbers

In term of lateral roots number, of both maize genotypes performed statistically similar (Table 4). However, Monsatno-919 produced slightly higher number of primary roots (17.86) as compared to Pioneer 30Y87 (16.6). The effect of irrigation treatments on primary root numbers was highly significant. Irrigation level I_2 produced significantly higher number of primary roots (20.83) which remained statistically at par with irrigation level I_1 (20.66). The lower primary root numbers were produced in irrigation level I_4 (13.66) and I_5 (14.50) followed by I3 (16.50). These results are in agreement with the findings of Zaidi et al. (2008) who reported that the lowest root growth in terms of primary root numbers were observed when numbers of irrigations increased as water availability normalize the extensive network of root system. The mutual effects of hybrids and irrigation level were found to be non-significant.

Effect of different irrigation scheduling strategies on primary root numbers was highly significant. Irrigation treatment I_2 produced significantly higher number of primary roots (20.83) which were higher but statistically at par with irrigation treatment I_1 (20.66). The lower primary root numbers were produced in irrigation treatment I_4 (13.66) and I_5 (14.50) followed by I_3 (16.50). These results are similar with Zaidi et al. (2008) who reported that the lowest root growth in terms of primary root numbers were observed when number of irrigations increased as due to maximum availability of water in root zone. The mutual effects of hybrids and irrigation level were found to be non-significant.

3.4 Lateral Root Length (cm)

Maize hybrids showed non-significant differences in root length (Table 5) from 451.6 cm (Monsanto-919) to 430.07 cm (Pioneer-30Y87). The response of Irrigation treatments to the root length was found to be highly significant. Irrigation level I_1 produced significantly more root length (548.67 cm) than the Irrigation treatments I2 (476.17 cm) and I_3 (434.33 cm). The minimum root length (363.67 cm) was produced by irrigation level I5 which is statistically at par with I4 (381.33 cm). It is clear from the above results that root length increases as number of irrigation treatments decreases. These results are similar with Zaidi et al. (2008) who reported that the lowest root growth in terms of length were observed when number of irrigations increased. The mutual effects of hybrids and irrigation level were found to be non-significant.

3.5 Root Dry weight (mg)

The effect of hybrids on the root dry weight was non-significant and there is no genotype variation with respect to root dry weight. Table (6) shows that in case of hybrids maximum root dry weight (0.61 mg) was attained by Monsanto-919 while minimum root dry weight (0.56 mg) was attained by Pioneer 30Y87. The effect of irrigation treatments on root dry weight was highly significant. Irrigation treatment I_1 attained maximum root dry weight (0.71 mg) followed by I_2 (0.67 mg) and I3 (0.59 mg) while minimum root dry weight (0.45 mg) was obtained by I_5 which was statistically at par with the root dry weight (0.51 mg) produced by I_4. These findings are in line with Zaidi et al. 2008 who reported that the lowest root growth in terms of root dry weight were observed when number of irrigations increased. The interaction between irrigation treatments and hybrids was non-significant. Usually it is noted in literature that proportional decrease in shoot biomass is much more than root growth in drought condition. (Benjamin et al., 2014).

Table 6: **Genotype variation in response to different irrigation scheduling strategies on root dry weight plant^{-1} of maize hybrids**

Treatments	Root Dry Weight (mg)
Hybrids	
H_1 = Monsanto-919	0.61
H_2 = Pioneer-30Y87	0.56
SX	0.03
LSD 5%	0.07
Significance	NS
Irrigations	
I_1 = Control	0.71 a
I_2 = 4 Irrigations	0.67 ab
I_3 = 6 Irrigations	0.59 bc
I_4 = 8 Irrigations	0.51 cd
I_5 = 10 Irrigations	0.45 d
SX	0.04
LSD 5%	0.01
Significance	**
Interaction	NS
Mean	0.6

Irrigation treatments: I_1 = Control, I_2 = 4 irrigations (6th 10th 14th 18th leaf stages), I_3 = 6 irrigations (6th , 10th,14th, 18th leaf stages, silking and blister stages), I_4 = 8 irrigations (6th , 10th,14th, 18th leaf stages, silking, blister, milking and dough stages), I_5 = 10 irrigations (6th , 10th,14th, 18th leaf stages, silking, blister, milking, dough, denting and physiological maturity). Means not sharing common letters in a column differ significantly at P = 0.05; NS=Non significant, * and ** are significant at 5% and 1% probability.

Table 7: **Genotype variation in response to different irrigation scheduling strategies on total dry mater (g m^{-2}) of maize hybrids**

Treatments	Total Dry Matter (g m^{-2})
Hybrids	
H_1 = Monsanto-919	5.89
H_2 = Pioneer-30Y87	5.95
SX	0.26
LSD 5%	0.57
Significance	NS
Irrigations	
I_1 = Control	5.28 b
I_2 = 4 Irrigations	5.44 b
I_3 = 6 Irrigations	6.18 a
I_4 = 8 Irrigations	6.18 a
I_5 = 10 Irrigations	6.42 a
SX	0.28
LSD 5%	0.63
Significance	**
Interaction	NS
Mean	6.04

Irrigation treatments: I_1 = Control, I_2 = 4 irrigations (6th 10th 14th 18th leaf stages), I_3 = 6 irrigations (6th , 10th,14th, 18th leaf stages, silking and blister stages), I_4 = 8 irrigations (6th , 10th,14th, 18th leaf stages, silking, blister, milking and dough stages), I_5 = 10 irrigations (6th , 10th,14th, 18th leaf stages, silking, blister, milking, dough, denting and physiological maturity). Means not sharing common letters in a column differ significantly at P = 0.05; NS=Non significant, * and ** are significant at 5% and 1% probability.

3.6 Water use efficiency (WUE)

The calculation of water use efficiency was based on crop evapotranspiration. Table (7) presents the effect of treatments on water use efficiency (WUE) for total dry matter (TDM) production (WUE_{TDM}) based on crop ET. WUE_{TDM} values were found to be non- significant between the two hybrids. The WUE_{TDM} produced by Monsanto-919 and Pioneer-30Y87 was 5.89 and 5.95 g m^{-2} mm^{-1}. Irrigation treatments showed significant effects regarding WUE_{TDM}. More WUE_{TDM} was obtained in treatments I_3 (6.18 g m^{-2} mm^{-1}), I_4 (6.18 g m^{-2} mm^{-1}.) and I_5 (6.42 g m^{-2} mm^{-1}). The water use efficiency for grain yield (WUE_{GY}) was also non-significant between the hybrids (Table 8). The values of WUE_{GY} for Monsanto-919 and Pioneer-30-Y-87 were 2.13 and 2.10 g m^{-2} mm^{-1}. The effects of the two cultivars regarding WUE_{TDM} and WUE_{GY} were non-significant which may be due to non-significant transpiration rates.

Table 8: **Genotype variation in response to different irrigation scheduling strategies on grain yield (g m^{-2}) of maize hybrids**

Treatments	Grain Yield (g m^{-2})
Hybrids	
H_1 = Monsanto-919	2.13
H_2 = Pioneer-30Y87	2.10
SX	0.15
LSD 5%	0.51
Significance	NS
Irrigations	
I_1 = Control	1.59 c
I_2 = 4 Irrigations	1.91 b
I_3 = 6 Irrigations	2.29 a
I_4 = 8 Irrigations	2.31 a
I_5 = 10 Irrigations	2.40 a
SX	0.90
LSD 5%	0.24
Significance	**
Interaction	*
Mean	2.14

Irrigation treatments: I_1 = Control, I_2 = 4 irrigations (6^{th} 10^{th} 14^{th} 18^{th} leaf stages), I_3 = 6 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking and blister stages), I_4 = 8 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking, blister, milking and dough stages), I_5 = 10 irrigations (6^{th} , 10^{th},14^{th}, 18^{th} leaf stages, silking, blister, milking, dough, denting and physiological maturity). Means not sharing common letters in a column differ significantly at P = 0.05; NS=Non significant, * and ** are significant at 5% and 1% probability.

As far as irrigation treatments are concerned, treatments I_3, I_4 and I_5 were good at producing more grain yield per unit water transpired. The ranges of statistically similar treatments were 2.29 to 2.40 g m^{-2} mm^{-1}. These results support the findings of Shah (2001) and Farooq et al. (2009), who also reported higher WUE_{TDM} and WUE_{GY} under higher number of irrigations. Similarly Ali et al., (2015) also reported higher yield of banana with increased irrigation levels.

4. Conclusion

It is concluded from the study that six and eight number of irrigations was economically good for the hybrids Monsanto-919 and Pioneer-30Y87. However, ten irrigations up to physiological maturity were statistically at par to these treatments in terms of grain yield and WUE. It would be wastage of resources if we apply more water beyond dough stage (6-8 irrigations). The response of irrigation scheduling to the root length were found to be highly significant. Irrigation level I_1 produced significantly greater root length (548.67cm) than the irrigation treatments I_2 (476.17cm) and I_3 (434.33cm).

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Competing Interests

The authors declare that there is no potential conflict of interest.

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